New bismuth-doped silica glass for LD-pumped ultra-short-pulse laser at 1.2-micron wavelength

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Abstract

Bismuth doped silica glass is a new material that emits broadband fluorescence peaked around 1.25 micron with a bandwidth over 300 nm. Absorption spectra are peaked at 500 nm, 700 nm and 800 nm with broad bandwidths of about 50 nm each. The fluorescence lifetime is about 100-600 μs depending on pump.

The fluorescence wavelength corresponds to the fiber communication band near zero-dispersion of a silica fiber. Its 800-nm absorption band makes this material potential to be pumped by the commercialized powerful laser diodes (LDs).

The LD pumped fiber amplifier at 1.3 μm showed 10 dB gain with 5-cm length and wide-band tuned amplification through over 100-nm bandwidth.

This report will review a state-of-the-art of bismuth doped silica laser material and its possibility to use as a short pulse oscillator with an LD pumping in place of the Ti:sapphire laser.

Research background of doped-silica glass for power photonics

ILE, Osaka

Issues	Parameters
Average power	High thermal shock parameter (100□5000 W/m) silica glass, ceramics (mainly YAG)
Peak power	High laser-damage threshold silica glass
High gain	Moderate emission cross-section (2□8*10^{-20} cm^2) Nd, Yb ions, disordered x’tal
Low nonlinearity	Higher Abbe number silica glass, fluorinate crystal
Low dispersion	Low index and low GVD silica glass
Scalability	Glass or Ceramics silica glass, ceramics, x’tal bonding

Laser material candidates for fusion driver in future

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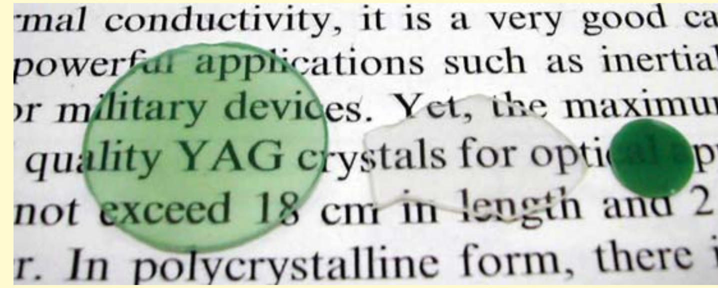
Nd doped silica glass

100-mm long Nd-doped silica glass

200-mm wide Nd-doped silica block by Vernueil method with zeolite-treatment

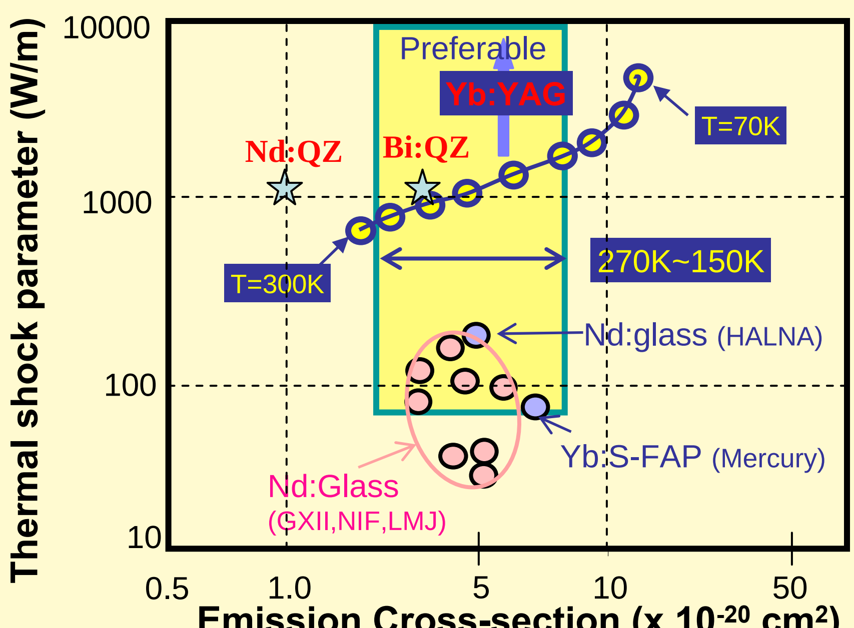
Transparent YAG ceramics



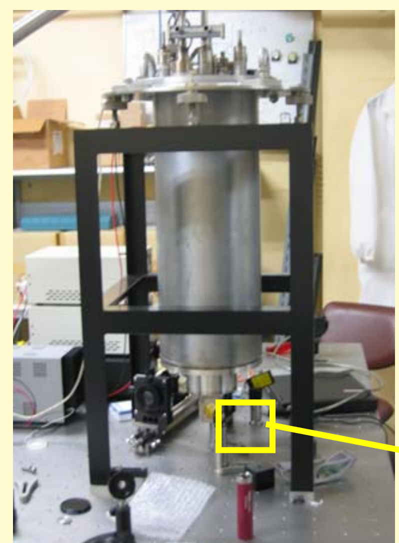
Liquid-phase process for powder, and
High temperature/pressure process for sintering

Nd:YAG, no-doped YAG, Nd/Cr:YAG

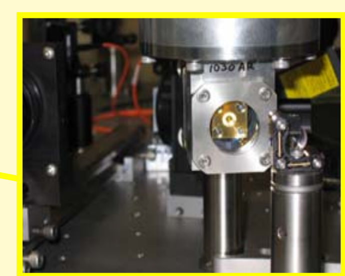
Parameter control of Yb:YAG by cooling a material temperature



Cooled Yb:YAG laser by Prof. J. Kawanaka



P_{out} = 75 W
η_{slope} = 80%



Zeolite-assisted Neodymium-doped silica glass

Zeolite:

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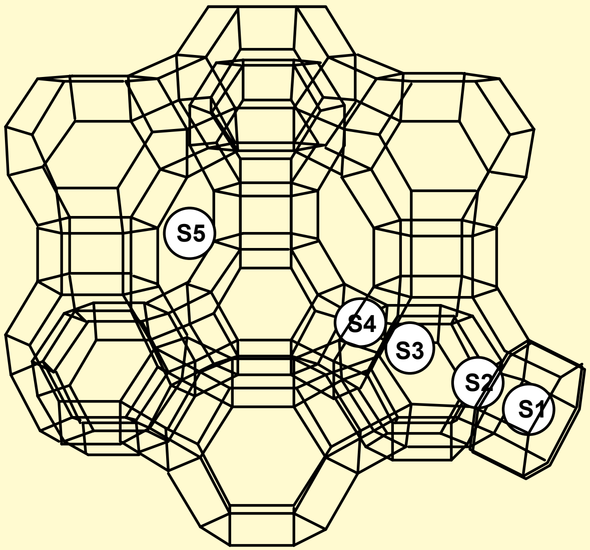
Any of a large group of minerals consisting of hydrated aluminosilicates of sodium, potassium, calcium, and barium. They can be readily dehydrated and rehydrated, and are used as cation exchangers and molecular sieves.

Unneccesary ions can be easily removed by chemical treatments.

Figure



Features

Five sites (S1~S5) exist in zeolite X which is occupied by ions.

There are 16 D6Rs in a unit cell. As zeolite X is dehydrated, exchanged ions tend to occupy the S1(D6R).

Crystal structure of Zeolite X is destroyed at 1000°C~, so it is expected that no crystallization occurs at sintering point (1750°C).

Zeolite X powder size is about 1μm.

Chemical treatment for ion exchange in zeolite

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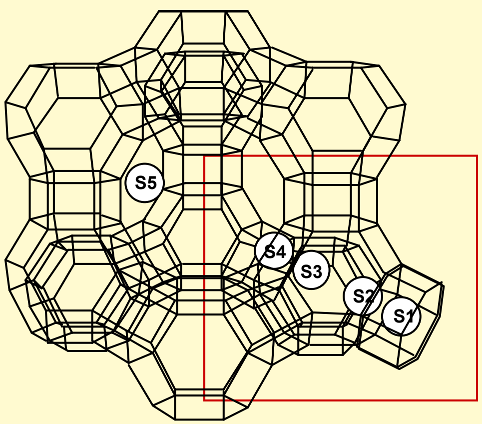
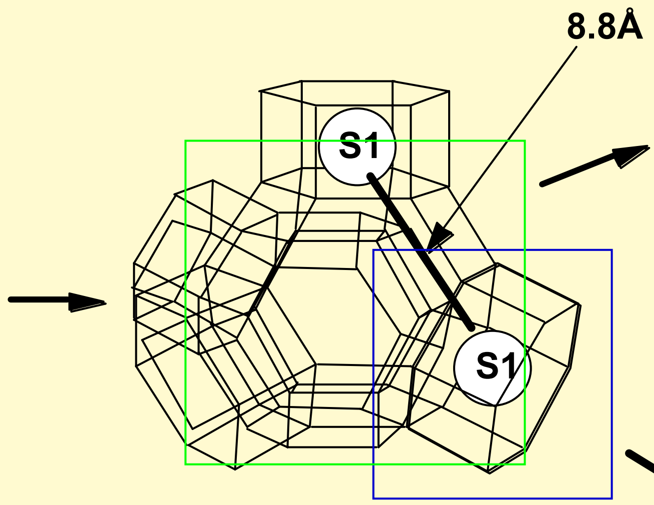
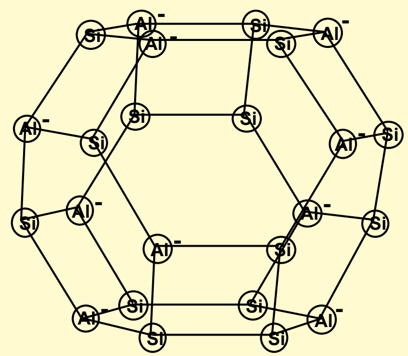
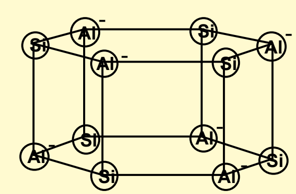




β-cage



D6R



Zeolite X ion exchange $Na^+ \rightarrow Nd^{3+}$

$Na_{86}[(AlO_2)_{86}(SiO_2)_{106}]\cdot 264H_2O \xrightarrow{\text{boiled at 100 ℃}} Nd_{28.7}[(AlO_2)_{86}(SiO_2)_{106}]\cdot 264H_2O$

(100% Nd-exchanged Zeolite X)

$\xrightarrow{\text{Saturated } NH_4Cl \text{ aq. treatment}} (NH_4)_{53.3}Nd_{10.9}[(AlO_2)_{86}(SiO_2)_{106}]\cdot 264H_2O$

We were looking for a type of poison atom to share cages in zeolite, then hit Bismuth.

Bismuth-doped silica glass

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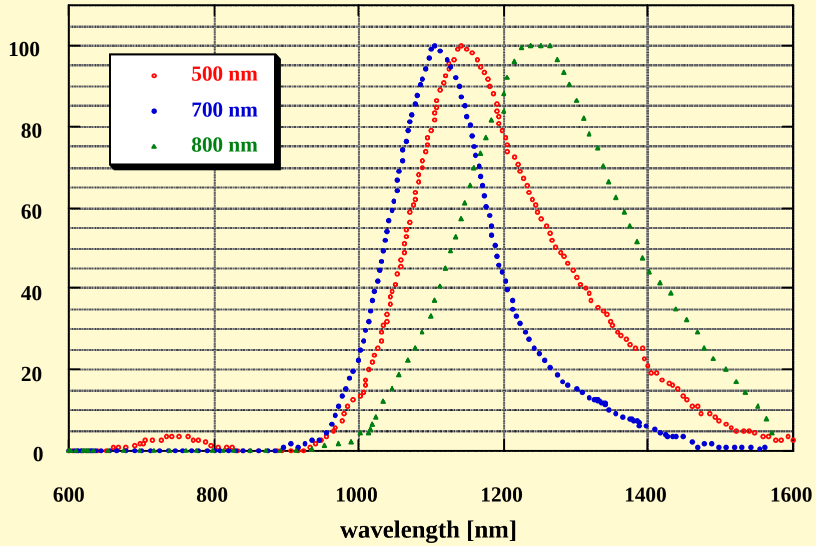
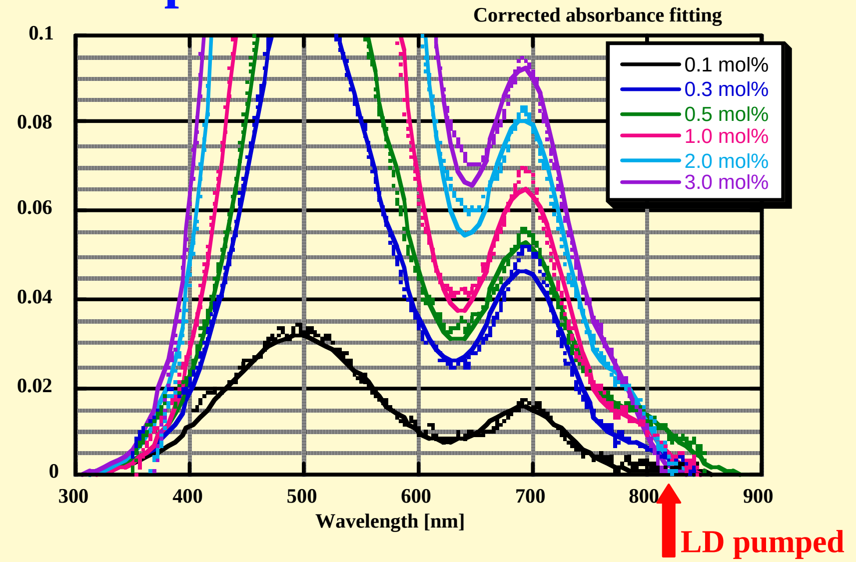
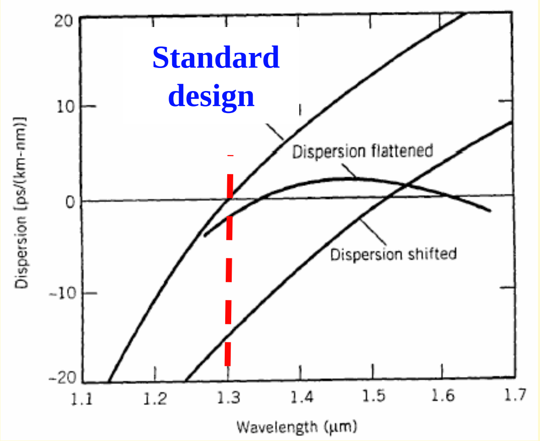
Fluorescence



Absorption



dispersion of silica glass fiber



zero dispersion

after Dr. S. Blair

The material features

800-nm LD pump,
broad fluorescence,
zero dispersion area,
thermally tough,
high gain

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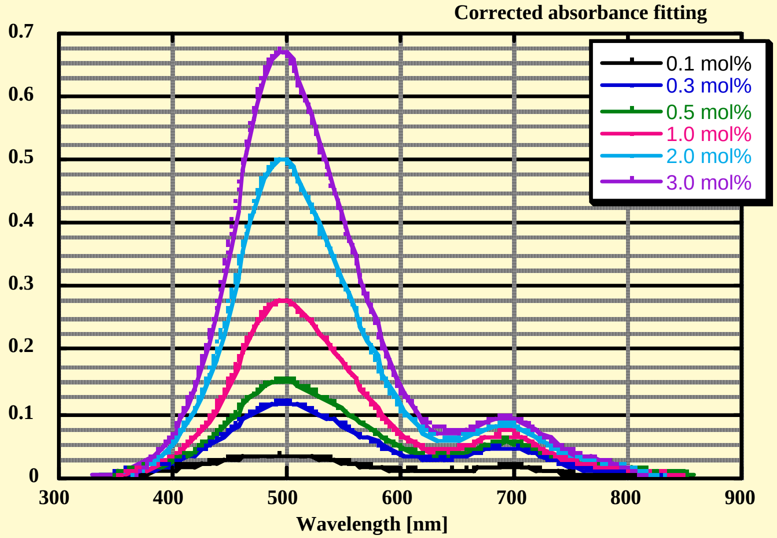
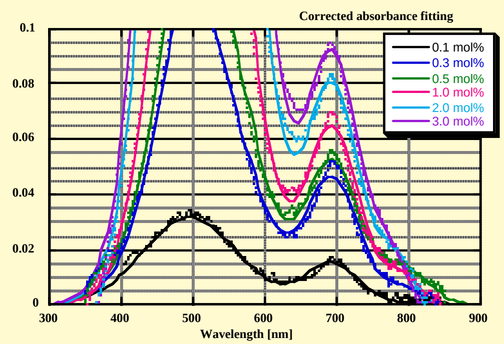
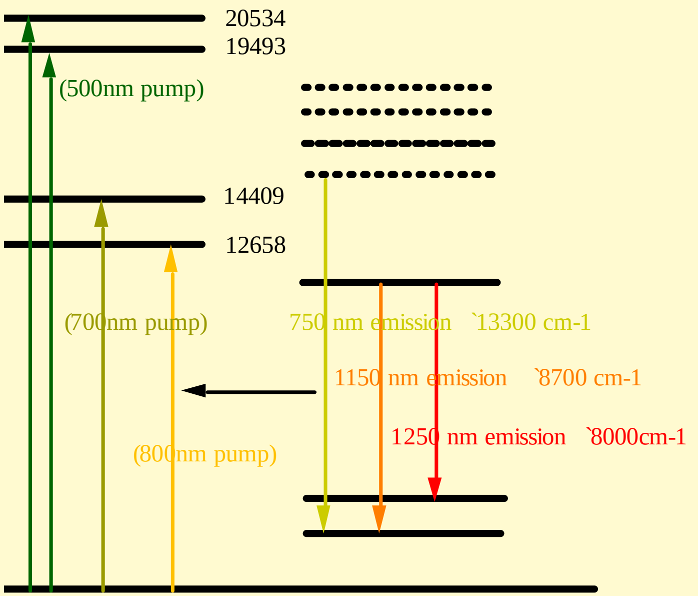
Absorption spectrum

Whole absorption spectra (dashed lines) of Bi/Al-doped silica glass for a parameter of doping rate with good agreements of fitting lines of four Gaussian peaks shown by solid lines.







Broad emission spectra for separated pump wavelength

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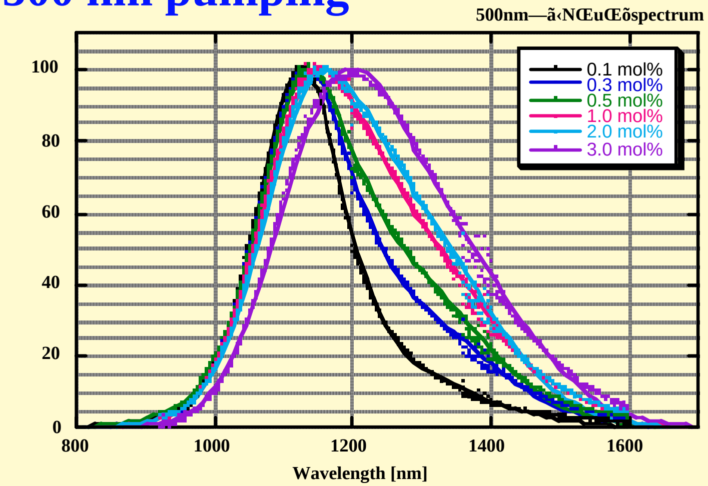
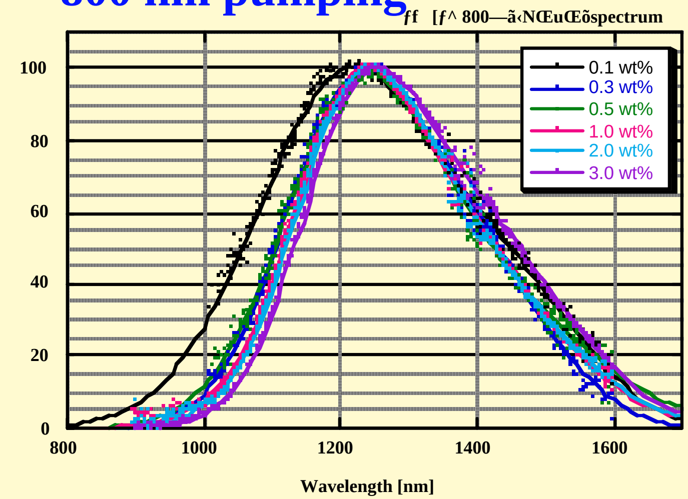
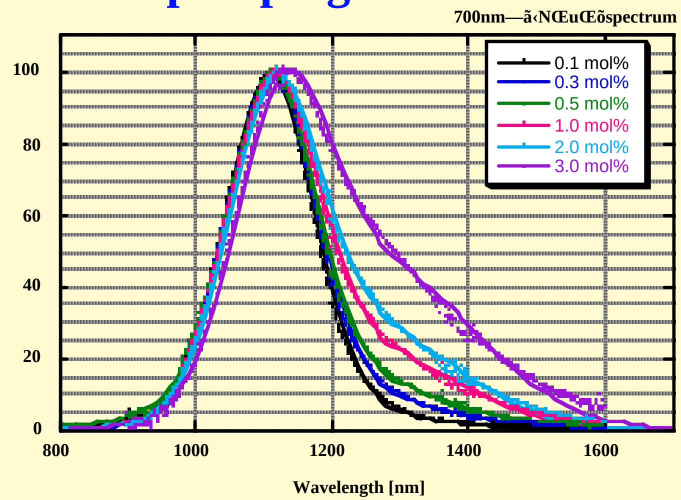
500 nm pumping



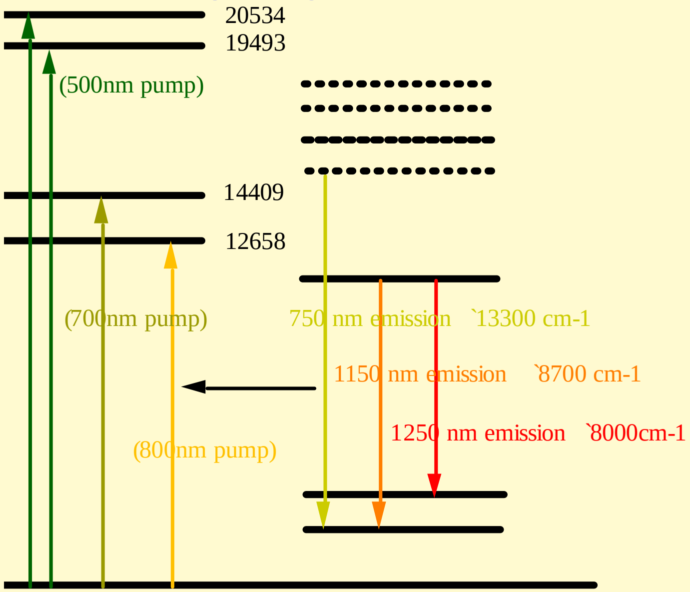
800 nm pumping



700 nm pumping



Energy diagram (tentative)



Lifetime of Bismuth fluorescence (fiber case)

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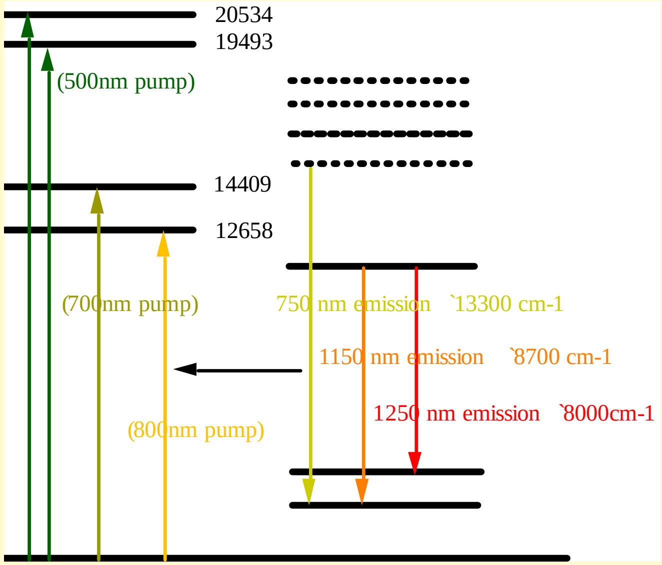
Lifetime of fluorescence at peak wavelength of Bi/Al-doped silica glass, a longer lifetime may results from 1150-nm band and a shorter one from 1250-nm band.

Excitation wavelength [nm]	Lifetime [μs]		Fitting
450	**149**	**683**	Double exponentials
700		**487**	Single exponential
833	**167**		

(collaborative work with Nippon Sheet Glass Ltd.)



Researches on Bi-doped glasses (not finished)

years	affiliation	item	feature	refs
1996 1997	ILE, Osaka, Japan	Zeolite assisted doping of ions to silica glass	First, Nd to Qz, then, Lanthanides ions, Various ions to zeolite cages	CLEO96, J. Non-Cryst. Solids
1999 2001	ILE, Osaka, Japan	Invention of Bi ion fluorescence near 1.2 μm	Covalent by Al ions, broad fluorescence @1200nm, Broad absorption from 500-800 nm	Fusion Eng. Design, J. J. Applied Physics
2003	ILE, Osaka, Japan	Fiber amplifier for 1.3 μm communication system	Melting point control, 10dB/5cm amplification gain, 2 waves amplification	
2004	Kyushu Univ. Japan	Bi-doping in modified silica glass	Broad emission, low temperature	
2004	China	Ge oxide glass,	Low melting glass, Fluorescence origin, Bi^{+},	Optics Letters
2005	Russia	Fiber amplification	MCVD, Low doping(<0.1%), 5W pump (1064nm), 400mW out, slope efficiency <14%	Quantum Electronics
2005	NSG/ILE	Fiber amp		
2005	Sumitomo, Japan	Bi-doped fiber	Low doping, Fluorescence and amplification, 190nm bandwidth @1.1μm	
2005	China	Many co-dopant	Fluorescence origin, Bi^{3+},	Optics Express
2005	ILE, Osaka	Co-doping with Erbium	Wide bandwidth over 550nm	Annual Report, ILE
2006	Russia	Fiber laser oscillation	Spectroscopic study	OFC/NFOEC 2006

Fiber laser @1.3 micron wavelength region

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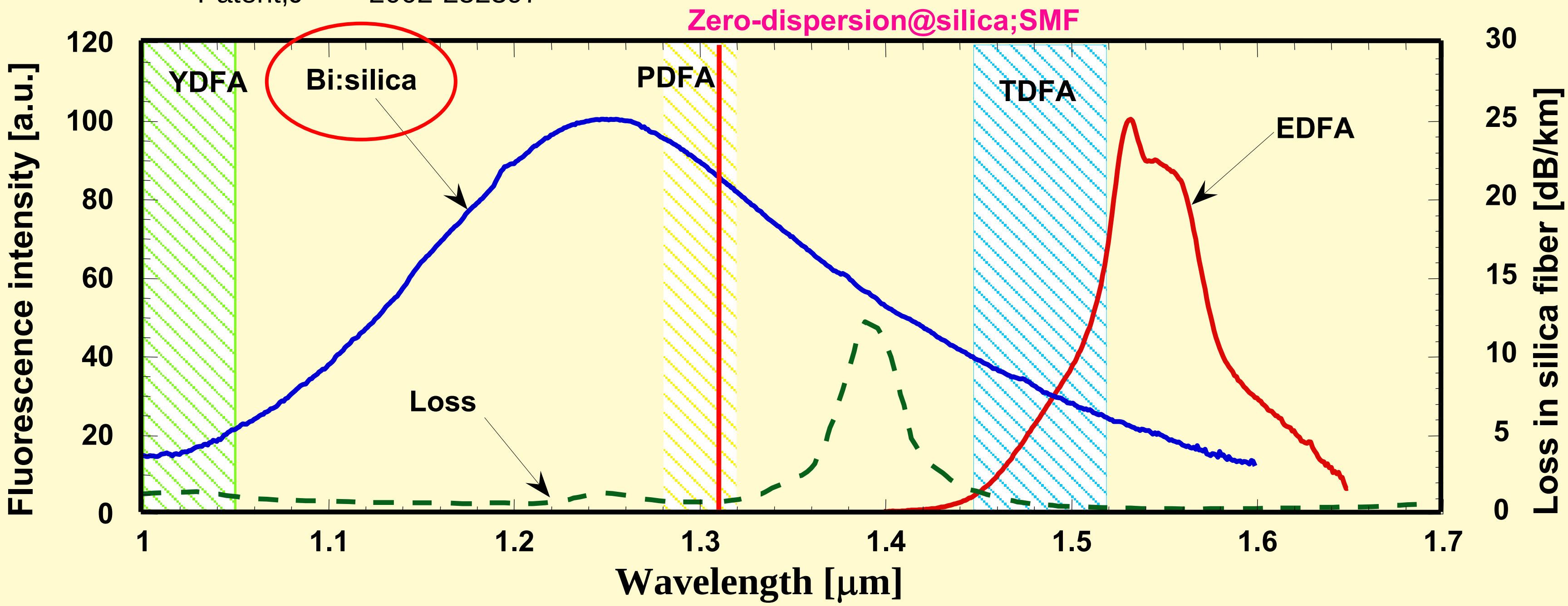
Patent;J 2002-252397



Advantage: wideband fluorescence of 300-nm bandwidth

dispersion-free region of silica glass, around 1.25 - 1.35 μm

800-nm band LD-pumping available

Characterization of Bi doped fibers

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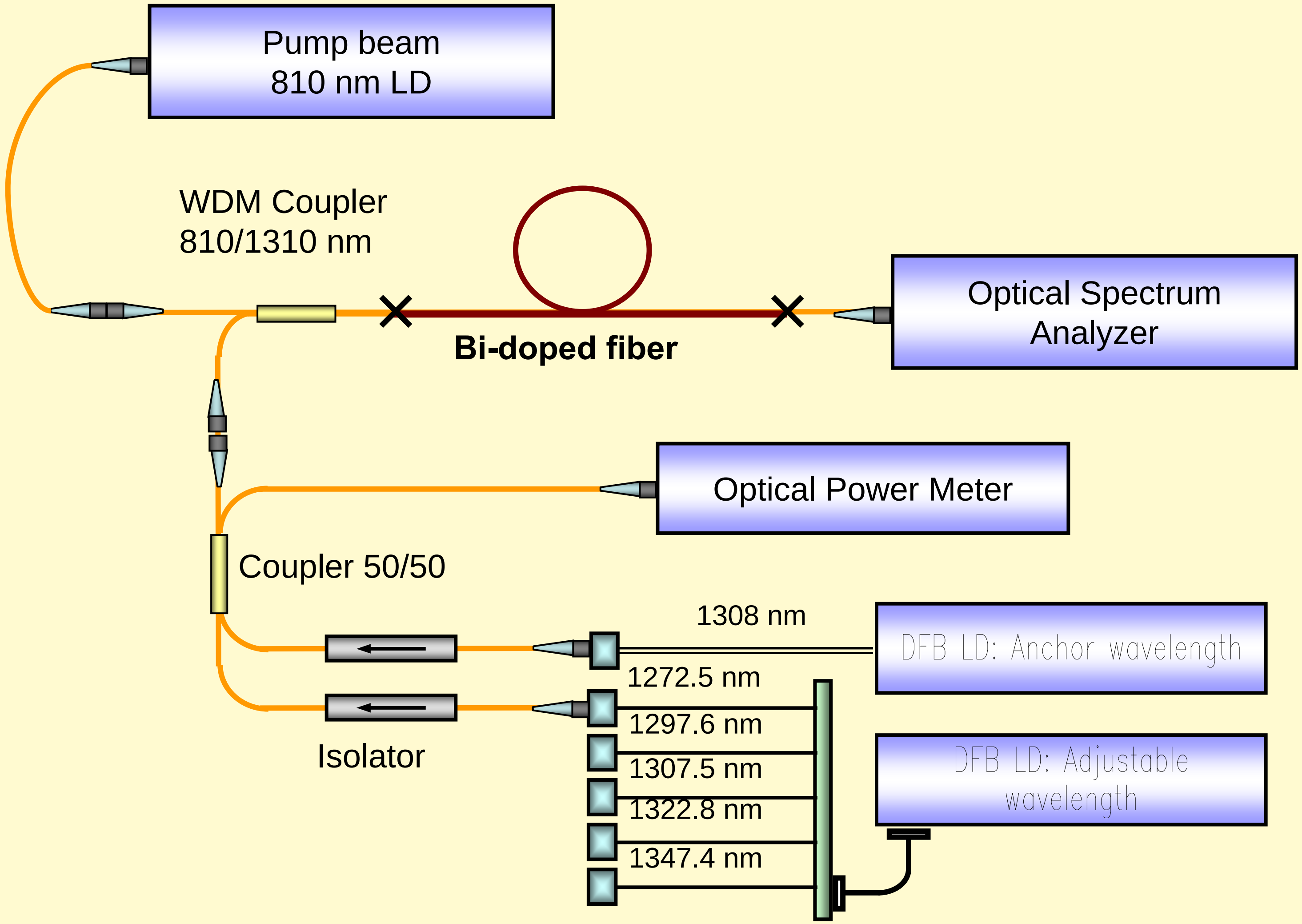

Multi-wavelength amplification of Bi-fiber lasers

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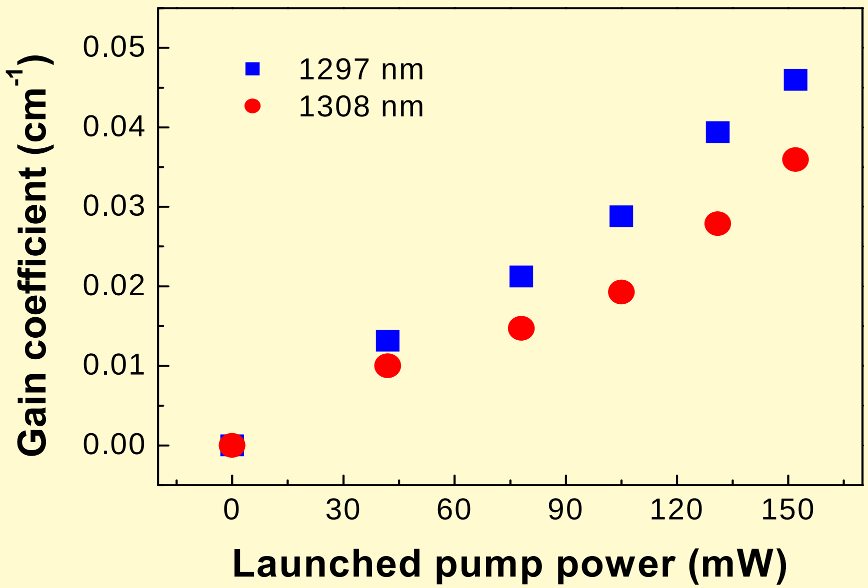
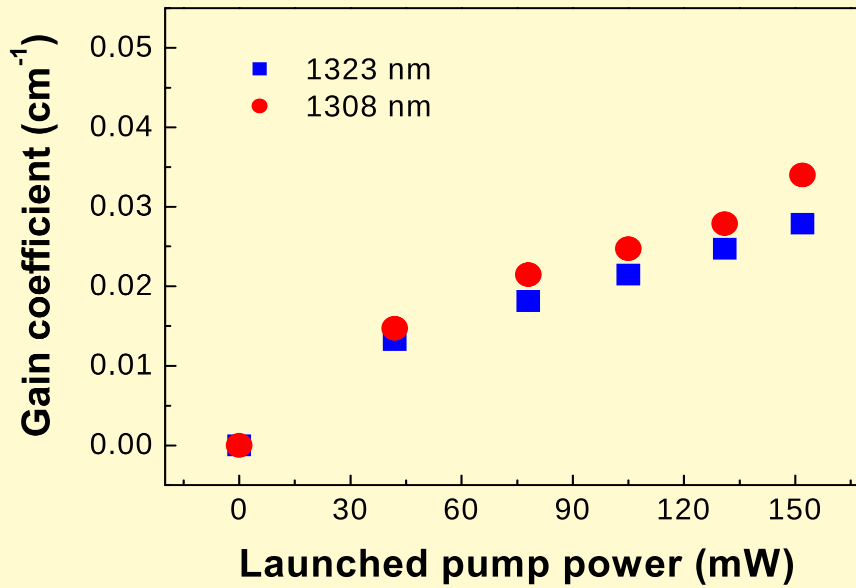
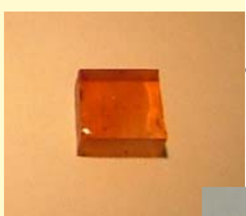
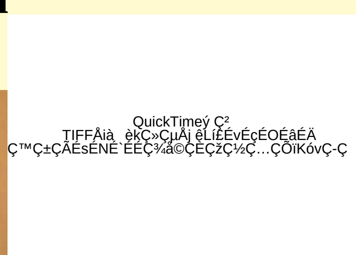




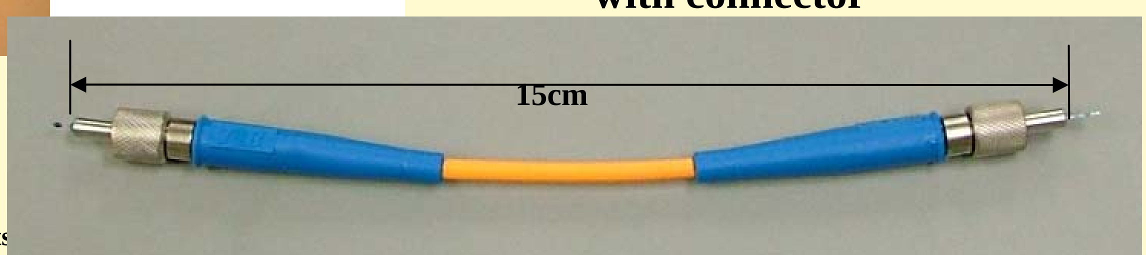
row material of Bi:silica

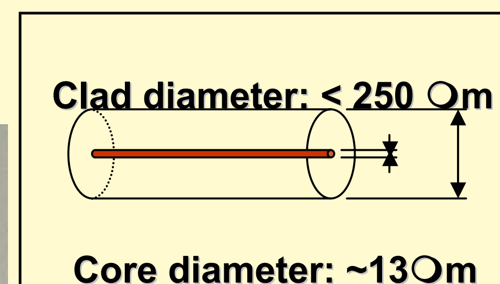




preform of Bi:silica fiber

Bi:silica fiber with connector





Emission-band broadening by co-doping of Erbium

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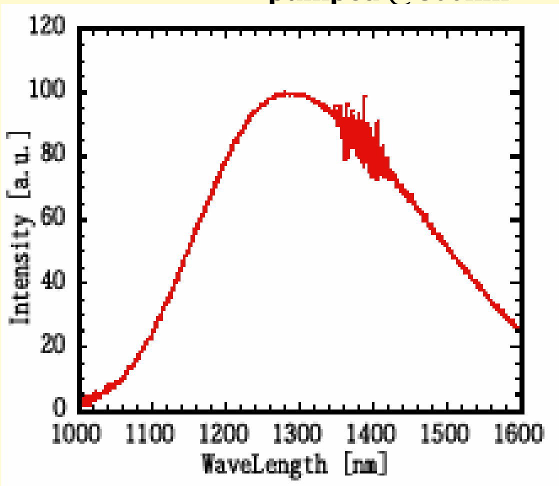
Bi:silica glass sample contains;

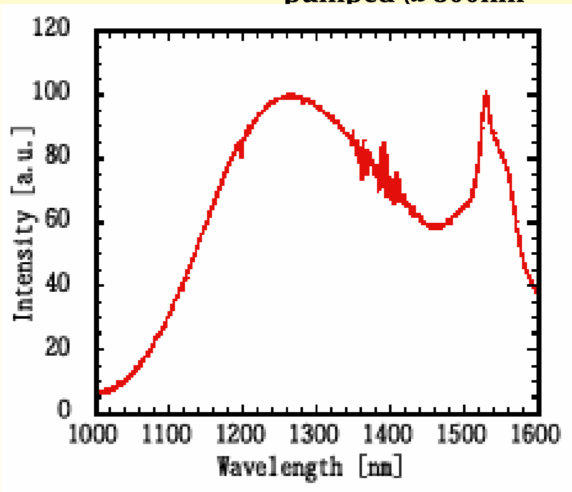
Bi/Al/Y/Ge/Ti,	Bi/Al/Y/Ge/Ti/Er,	Bi/Al/Y/Ge/Ti/Er
pumped @800nm,	@800nm	@920nm
Bandwidth 350nm (6.1THz),	440nm (77THz),	540nm (110THz)

Ti:sapphire has a FWHM-bandwidth of 180nm (86THz) peaked @790nm.

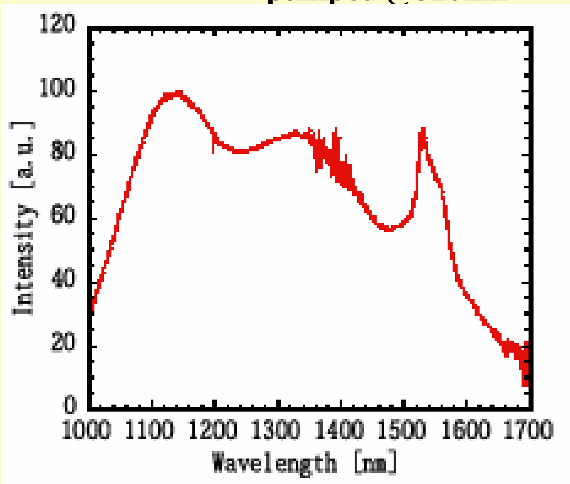
pumped @800nm



pumped @800nm



pumped @920nm

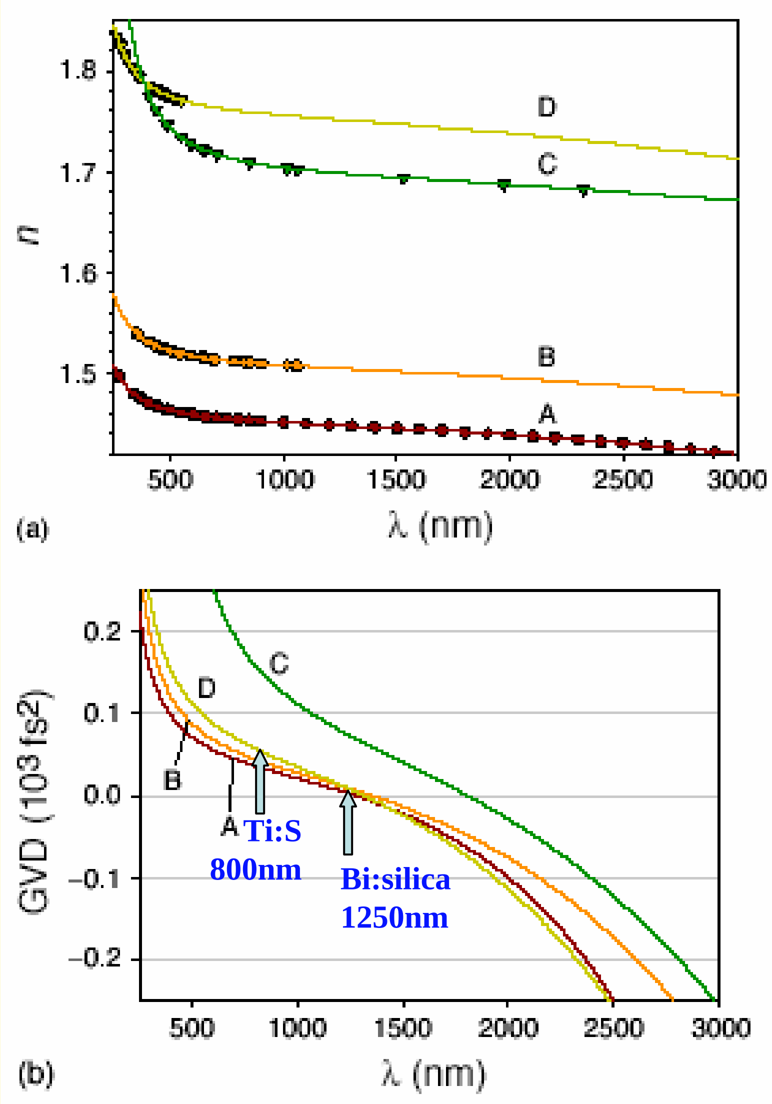


Index dispersion spectrum of Silica glass and Sapphire

(A) Fused silica, (B) Schott BK7, (C) Schott SF10, (D) sapphire. after G.D. Reid & K. Wynne

(a) Data points and Sellmeier fit line.

(b) GDD for 1-mm thick material.



after G.D. Reid & K. Wynne

Dispersion property of laser media

Ti:Al_2O_3; 60 fs^2 @800 nm

Bi/Al:silica glass; 6 fs^2 @1250 nm

Issues on fabrication of Bi-Qz glass

High melting temperature of quartz glass

intrinsically over 1750□, but glass modification is available for getting lower melting point.

High vapor pressure of Bi-oxide

melting point is 1100□, then concentration control of Bi ions is difficult.

Homogeneity of quartz glass

3-D homogenization process is needed by Shin-etsu Silica Glass.

Unknown physics of Bi-Qz glass

What is an origin of emission near 1.2 micron, Bi^{5+} or Bi^{3+} ?
Energy levels are not confirmed yet in detail.
Lifetime is very longer, 200-600 μs than Ti^{3+}:Al_2O_3, 5 μs.

Short pulse generation of Yb doped silica fiber laser

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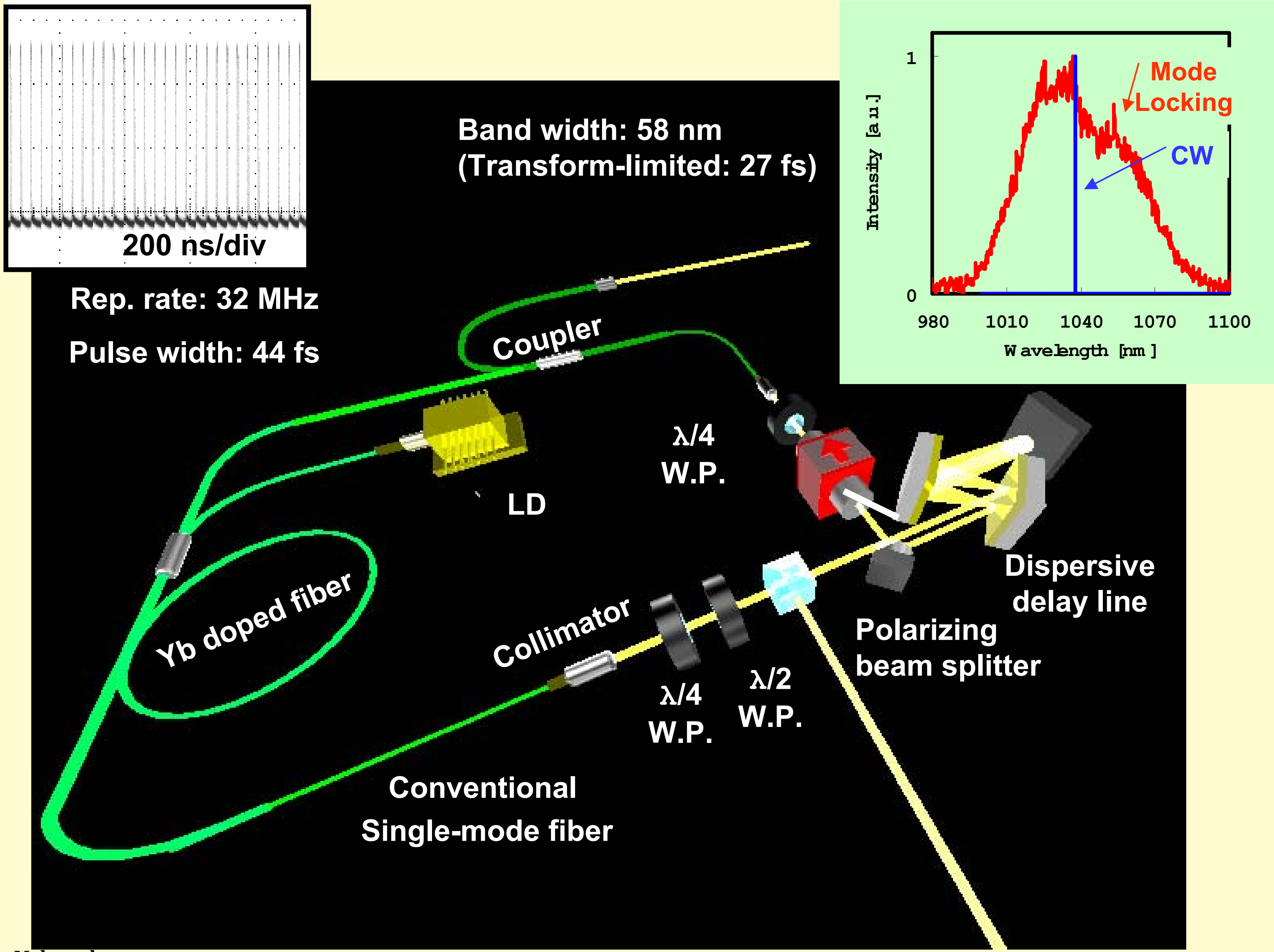

Example of staging for short pulse laser system

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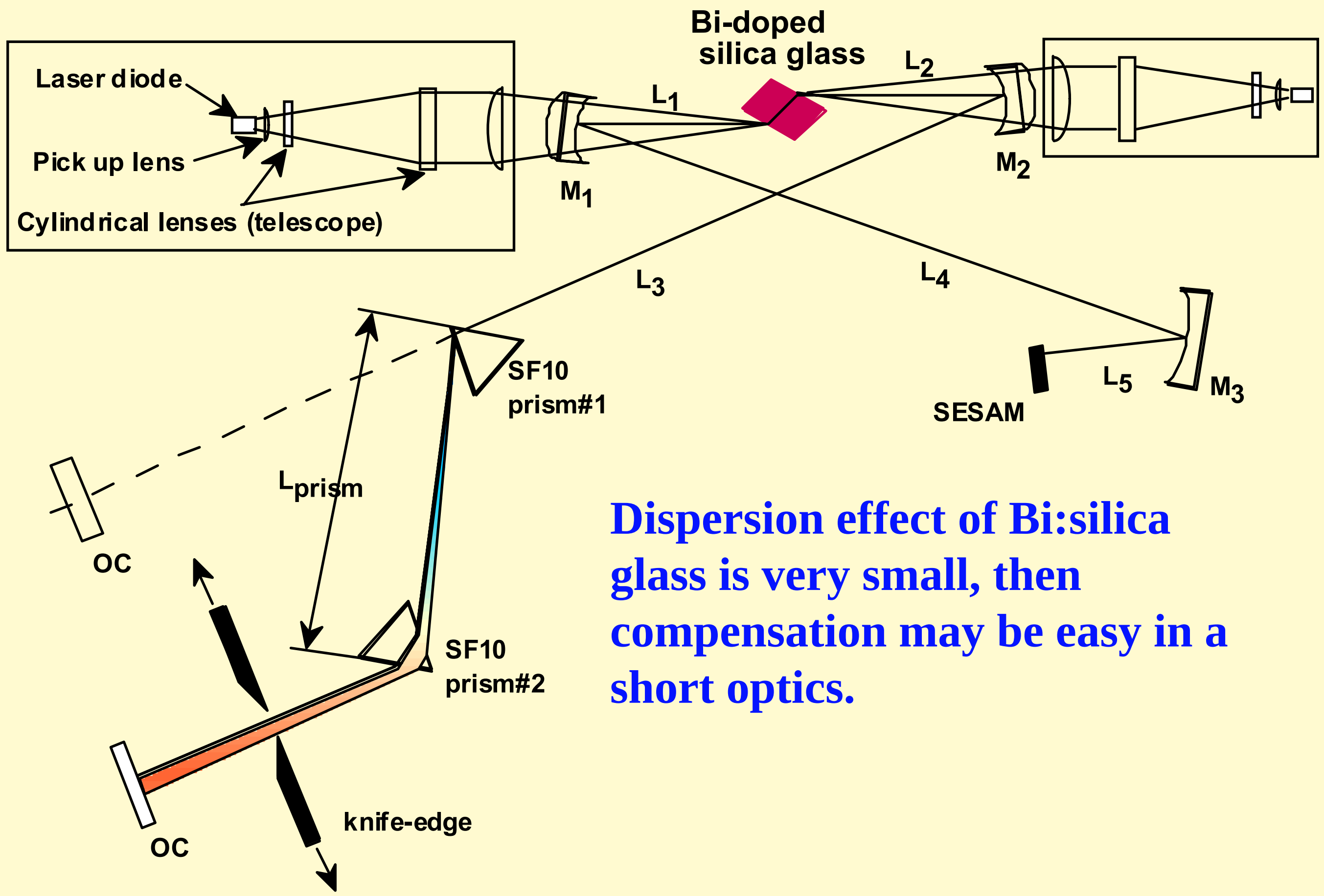

Dispersion effect of Bi:silica glass is very small, then compensation may be easy in a short optics.

Summary

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1. Volume silica glass is a candidate of average power laser material fabricated by Verneuil method

2. Many fluorescent ions can be doped dispersive in silica glass by zeolite-assisted method.

3. Bismuth and Aluminum ions can be co-doped in silica glass.

4. Bi ion emits near infrared fluorescence, 1250-nm band, which is near zero dispersion area in a silica glass.

5. Bandwidth of Bi-fluorescence is very broad, 300-550 nm. And wideband amplification was verified by the fiber amplifier experiment.

6. Absorption band of Bi ions includes 800-nm region corresponding to a wavelength of high power LD pumping.

7. Lifetime of Bi:silica fluorescence is 100-600 μs.

8. In conclusion, Bi:silica will work as an efficient and low-cost ultra-short pulse laser overcoming Ti:sapphire laser pumped by Nd:YAG SHG.